Recent Developments in the Naval Oceanographic Office Survey Operations Center

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***Abstract*—The Naval Oceanographic Office (NAVOCEANO) operates a fleet of seven multidisciplinary survey ships deployed throughout the world dedicated to collecting hydrographic and oceanographic data. Leveraging commercial off-the-shelf (COTS) communication, network, enterprise management, and system integration technologies, NAVOCEANO developed a Survey Operations Center (SOC) focused on the continuous improvement of survey quality and reduction of the time required to deliver product to clients. The COTS components include rsync as a file replication system, IBM MQ Series as a real-time message bus, and Computer Associates Unicenter as an enterprise management system. In addition, Perl is used as an integration language, and various web/visualization and database technologies are incorporated into the design. The SOC infrastructure was initially developed to support both continuous asymmetrical high bandwidth (2.048-Mbit ship to shore/384-Kbit shore to ship) and was subsequently adapted to support dial-up symmetrical low bandwidth (64-Kbit) communication links.**

This paper reviews the technical aspects of the SOC infrastructure to be implemented into the operational environment in 2003 and beyond. It concentrates on the COTS technologies that were assembled into a unified system, how the system was connected to the existing ship data acquisition systems, and information transport mechanisms. It also covers changes in the bandwidth requirements, implementation schedule, as well as the use of enterprise management, network management tools, and web and other technologies to make the information available to the scientists throughout NAVOCEANO.

I. INTRODUCTION

The Naval Oceanographic Office (NAVOCEANO), located at Stennis Space Center (SSC) Mississippi, is the home of the U.S. Navy's operational support unit for oceanographic and hydrographic data collection. NAVOCEANO is the field activity for the Commander, Naval Meteorology and Oceanography Command, who reports to the Oceanographer of the Navy on the Chief of Naval Operations Staff.

NAVOCEANO operates a fleet of seven survey ships built from the keel up to support military surveys. These ships are equipped with numerous hull-mounted underway oceanographic sensors and also have roll-on, roll-off capability for specialized scientific packages (Fig. 1). The vessels are permanently forward deployed and after construction may never see a U.S. port during their years of service. NAVOCEANO scientists, technicians, and engineers routinely deploy to these ships for periods of one to three months to conduct scientific surveys that support validated Fleet requirements.

In accordance with NAVOCEANO's philosophy of characterizing the battlespace for the warfighter, the data collected by its civilian scientists and engineers are used for navigation charts and model inputs and then warehoused in databases that subsequently feed Fleet Tactical Decision Aids (TDAs). Water-column data (temperature, salinity, sound-speed), bathymetry, ocean acoustics, optics, bioluminescence, currents, tides, digital side-scan sonar, and hydrographic information for safety of navigation are just some of the types of data collected by NAVOCEANO. Again, the overall function of the Office is to better define the battlespace environment for the warfighter.

II. REQUIREMENT FOR THE SURVEY OPERATIONS CENTER (SOC)

NAVOCEANO has recently developed a new approach to improve overall efficiency and response time to our Navy customers. Moving the data collected aboard our survey ships back to the Office for product generation under the existing Concept of Operations involves copying the data off disks to portable magnetic media at the end of the survey and shipping or mailing these data back to NAVOCEANO. This can be a time-consuming and lengthy process, especially when the survey is being conducted on the other side of the world. Once the data arrive at NAVOCEANO headquarters at SSC, Mississippi, the data are queued up from tape onto the Data Ingest System and put on line, where the data are made available to scientists and analysts. The entire process, from data collection to data availability, may take as long as two to five months, considering mail delays and data backlogs. By this time, the survey vessel has likely moved out of the area and been tasked with other surveys. If there is a problem with the data, getting permission to resurvey the area must be renegotiated.

In addition to these data access delays, the survey sensor systems themselves are becoming more complex, resulting in a larger volume of data collected. Some of the T-AGS 60 class survey ships are equipped with two hydrographic survey launches (HSLs). These HSLs work up to eight hours a day (they are limited to daylight operations), tow digital side-scan sonars, and run hull-mounted shallow-water multibeam sonars. The T-AGS 60 vessel combined with its two HSLs is capable of generating 150 gigabytes of data in a 24-hour period. Considering the tremendous investment of resources and expense of field data collection, efficiency must be maximized, and data rework must be kept to a minimum.

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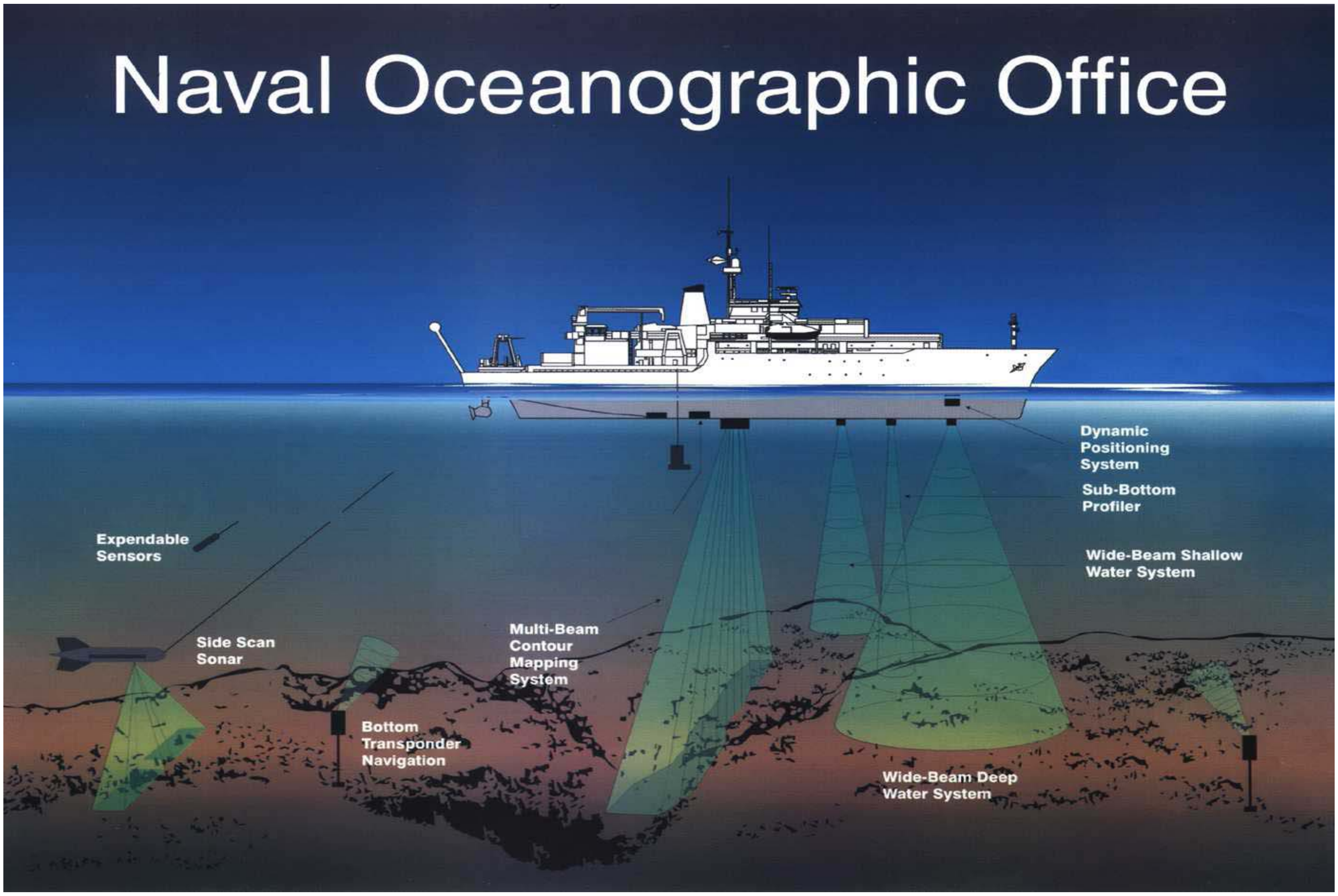

Fig. 1. T-AGS 60 Class Survey Ship

Centralized, high-speed satellite connectivity to the survey ships would address these issues by (1) delivering the data to the Office sooner, and (2) allowing Subject Matter Experts (SMEs) to review the data in near-real time. To address these concerns, NAVOCEANO has established a SOC. A high-speed communications link would allow critical data to be moved back to the Office in near-real time for faster product turnaround. Having the data enter the Office through one control room, operating around the clock, would allow resident SMEs to review the remote survey data in near-real time as the data pass through the SOC. This technology, introduced by the SOC Subsystem (SOCS) infrastructure, would enable the resident experts at the NAVOCEANO headquarters to become virtual members of the survey team. With the addition of video teleconferencing to the system, experts on survey platforms in other parts of the world could even be brought to bear on specific shipboard problems on another platform. NAVOCEANO installed the first of these high-speed communications systems aboard the USNS PATHFINDER in April 2001 and successfully demonstrated the data telemetry to the SOC the following June. Construction has recently been completed at SSC for a new state-of-the-art control room facility with over 4500-sq. ft. of space dedicated to the SOC.

As previously noted, the volume of data these platforms are capable of generating is staggering. With seven ships operating simultaneously, the bandwidth necessary to move all data back to the SOC in near-real time is cost prohibitive. As a result, a tiered approach to the data was devised during the Proof of Concept (Fig. 2). The most cost-effective link was found to be an asymmetric 1 megabit per second (Mbs) connection ship to shore and a 256 kilobit per second (Kbs) link shore to ship. This relatively high bandwidth allows for the transportation of critical survey data and also Voice Over Internet Protocol (VOIP), e-mail, Web access, and video teleconferencing. This marine high-bandwidth communications technology is currently being used in the cruise ship and offshore oil exploration industries. In our case, however, all data were encrypted before leaving the ship.

Depending on the survey mission, the highest priority data are the data that affect the overall quality of other data being collected. For example, if the survey mission is multibeam bathymetry, the in situ sound-velocity profile applied to the swath sonar system is critical to optimum sensor performance. Water column data (temperature/salinity/sound velocity) are relatively low volume but highly critical to successful multibeam performance. This was always transmitted back. The multibeam bathymetry data, which are

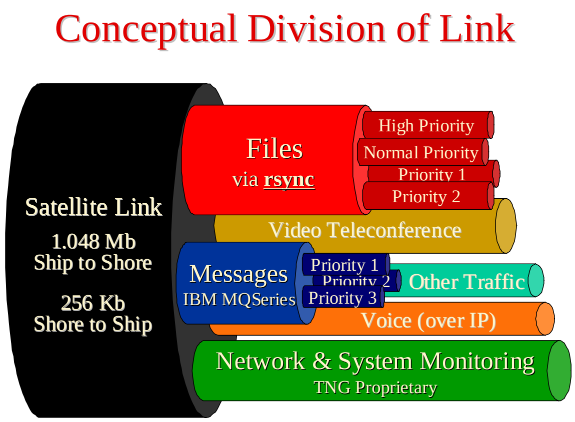

Fig. 2. Conceptual Division of Link

higher volume, was also transmitted through the link. Again, the objective was to have the data reviewed in a near-real-time fashion by scientists at NAVOCEANO headquarters. The SOC then functions as a supplemental asset to the field survey effort.

III. SOC LOW-BANDWIDTH AUGMENTATION PROJECT (SLAP)

The expense associated with the high-bandwidth communications link is significant. These expenses include space segment, earth station downlink, and terrestrial lease fees, all at 1 Mbs from the ship to SSC and a 256-Kbs return link. NAVOCEANO decided to proceed with an incremental roll-out plan for fielding these shipboard antenna communications systems. This roll-out plan concentrates on re-establishing the high bandwidth link with the USNS PATHFINDER in the summer of 2003, installing antennas on two ships in the Pacific Ocean Region during 2004, and adding two ships (one in the Indian Ocean Region and one in the Atlantic Ocean Region) in 2005. In 2006, the last T-AGS 60 class ship will be equipped in the Indian Ocean Region. In the short term, however, we have concentrated on the development of the shoreside system utilizing the existing high bandwidth subsystem to work over the existing Inmarsat B 64-Kbs communication link. It is substantially more expensive per megabyte to transfer data over Inmarsat B, so the focus here is on quality metadata. Maximum attention has been given to reduce the volume of data by subsetting large data sets and pushing as much of the pre-processing and data compression as possible to the ship.

The metadata of interest is replicated in the field from the Integrated Survey System (ISS-60) data acquisition system to the new rack-mounted, shipboard Quality Management Server (QMSB1). From this location, data of interest are transferred to the NAVOCEANO SOC Unclassified Data Cache in an interim manner, based on its priority. The connection is initiated by the ship but controlled by the SOC through a configurable file that is pushed to the ship at link initiation, which tells the remote unit when to call next, what to send, and file size limitation. By altering this configuration file between phone calls, the SOC retains the flexibility to request additional data streams as engineers, scientists, and analysts review the metadata coming across the link. Unless terminated by the communication "watchdog" application, critical priority data are returned each time the ship establishes a link to the SOC. High, medium, and low priority data are returned only during the times scheduled for such data, as indicated in the control configuration file.

Prior to replication from the new ship-based QMSB1, additional value may be added to the data acquired from the ISS-60 or other survey ship system. This additional processing occurs during the extended periods when the ship and the SOC are not connected and may include executing validation and processing applications or compressing or otherwise preparing the data for transport to the SOC. Thus, the design enables the future development and integration of shipboard validation and processing applications into the overall SOC system.

Once transported to the SOC, the data will be ingested into the existing shoreside SOC environment, which was delivered to NAVOCEANO in April 2001. The existing receiving system is configured for unclassified data only. Since classified and unclassified data must travel on separate, isolated networks, in 2003 NAVOCEANO incorporated a mirrored classified receiving system into the SOC information technology (IT) infrastructure. The SLAP modifications will be configured to maximize the value of the low-cost link, while ensuring that the limits may be specified to control overall cost.

IV. SURVEY CENTRIC VIEW (SCV)

Once the quality metadata arrive in the SOC from the ship, they must be managed, distributed, and tracked within the NAVOCEANO business/validation process. The SCV is the integration design that enables the SMEs to view the metadata after they have been successfully transferred across the link. There were several important requirements. The SCV needs to provide an operator interface that:

- Enables the viewer to quickly access the progress and quality of the specified survey.
- Allows the user to tailor the aggregation of the information to provide an assessment that addresses the needs of the user.
- Provides a "jumping off" point enabling the user to drill down to obtain the level of detail required by the user.

The SOC, in its role as an Enterprise Management System, is designed to collect and assimilate information from an enterprise perspective. Information concerning the health and operation of systems and components throughout the SOCS (which includes systems on the survey ship, the network itself, and the systems in the SOC facility) is collected by the SOCS. Network and system status/events are merged with the status and messages produced by the remote survey systems, providing a central IT subsystem responsible for displaying and responding to all messages. Tools are provided to view this information from physical, logical, and other enterprise centric perspectives. To illustrate this concept of views, let's examine one of the many sensor

systems aboard the survey ships, the underway bioluminescence sensor system (BIOLITE). Fig. 3 presents the logical BIOLITE workflow process, annotated with the SOC monitoring points and two sets of displays collected into Survey Centric and Enterprise Centric perspectives, or views.

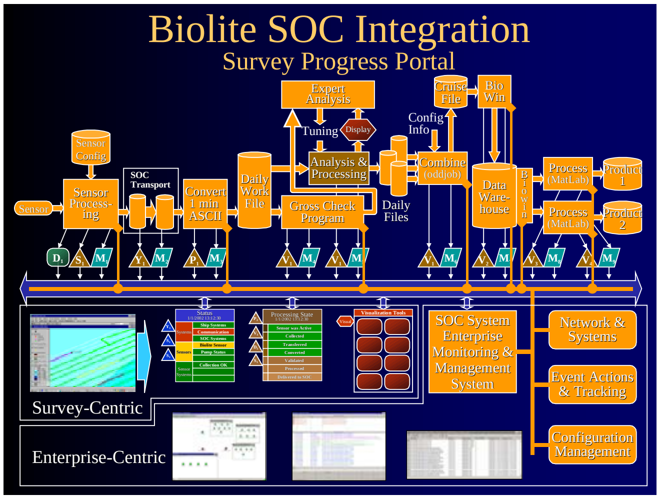

Fig. 3. Relationship of Views

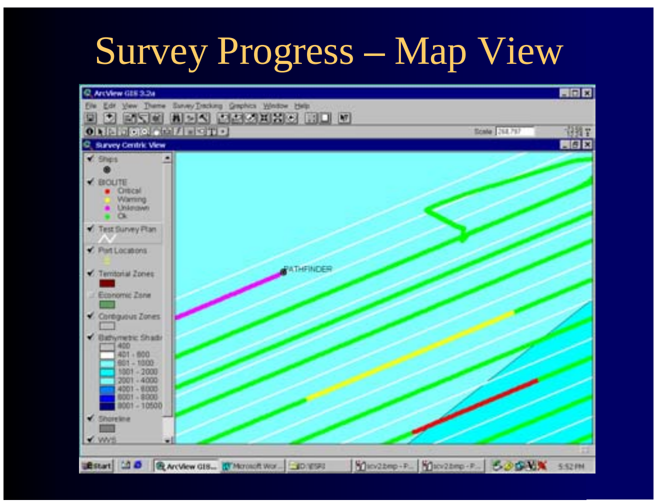

Fig. 4. Survey Centric View Display

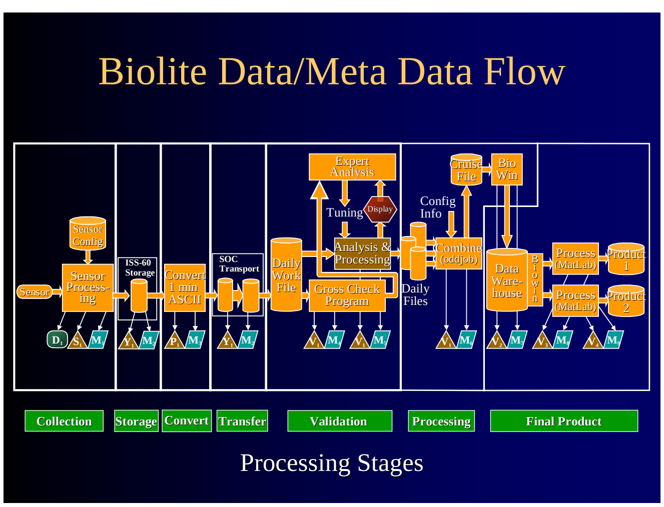

Fig. 5. BIOLITE Process Stages

The collection of displays that comprise the enterprise centric view provides important insight into the operational status of the system from perspectives necessary for network and system managers. This enterprise centric view also provides NAVOCEANO personnel the ability to view statuses and events across platforms, providing for the first time an easy way to view information from all the same sensor type on all ships simultaneously.

While the enterprise centric view is valuable, NAVOCEANO scientist and engineers are more focused on a single ship or quality metadata from a single survey operation, which are not typically available from an enterprise perspective. The assessment of the progress and quality of a survey requires monitoring many pieces of information. Some of the key items for the initial assessment include:

- Ship position and track as it relates to the survey plan.
- The status of all available shipboard survey sensor systems.
- The status of all sensor systems required for success of the survey as identified in the survey specification.
- The successful archive of the sensor status information regarding ship systems.
- The results of automatic or manual shipboard data validation or processing.
- The successful transportation of the data across the link to the SOC.
- The results of automatic or manual validation provided by the SOC or the SMEs at NAVOCEANO.
- The delivery of the product by the SME to the product distribution group.

V. THE SCV DISPLAY

The role of the SCV display is to assimilate all this information into a single view. Fig. 4 presents an example display. Note that the dots representing status and process information are presented on one layer. Other layers could show the track of the current survey plan the ship is executing, the territorial waters/exclusive economic zone information for the host nation, and could even show the locations of profile information, such as CTD and XBT taken in the area, to characterize the water column for sound velocity purposes. The following concepts are key to the SCV summary display.

Time quantum. Each dot along the survey track represents the status of the data for a particular unit of time. This time unit begins immediately after the quantum represented by the previous dot and continues through and ends with the current dot. Time quantum is the primary reference to the data (not position). The quantum to display is selectable, currently hour and quarter hour. (Support exists for one-minute quantum, but this dataset is not yet being populated.) Information is collected and summarized for the entire quantum. That is, the one-hour quantum for a sensor

TABLE 1.
DOT COLOR TABLE

Color	State	Description	Value
None	Undefined	Not initialized	0
Green	OK	Good	1
White	Unmonitored	State not monitored and will not be known	2
Purple	Unknown	State unknown at this time	3
Yellow	Caution	Caution state	4
Orange	Error	Error state	5
Red	Severe	Serious error	6

status indicates the worst status encountered during that hour (not the instantaneous value at the end of the hour).

Time/Position correlation. The coordinates of a dot are at the trailing transition, that is the location of the ship at the end of the quantum.

Dot color/state. A dot may be one, and only one, of the following colors. Each color represents a state. Each state has a value; the higher the value, the more serious the state. (See Table 1.)

Process Depth. As illustrated by Fig 5, data being tracked originate with their collection by a sensor system and are passed through a series of processes until they become a product. Typical process depths (listed in order) include sensor, shipboard storage, shipboard processing and validation, real-time transport, shore-based validation, shore-based processing, and product delivery.

Process Flow. The process flow contains a single thread and does not support branching. The logical process travels downward. That is, collection by the sensor is at the top, and the resulting product is at the bottom. Fig. 5 depicts an overview of the BIOLITE workflow. Logical flow is left to right.

Fig. 6 depicts the progress of data through the business process as time progresses. Note, information on the status of processes beyond the collection depth is not known until after quantum closing time has passed and must thus be "back filled" with status information when it becomes available.

Process Flow Layers. Fig. 7 depicts a possible scenario for a series of five quantum and the colors that could be assigned to the dots associated with these quantum when drawn on the BIOLITE SCV process layers. A row in this figure is the time series view of the quantum, which is combined with the quantum's position information to generate a single survey progress layer. Each square in this figure represents a status value reported by the system for the specified quantum. The color is derived from Table 1. The "current" time is represented by the right tip of the time arrow and projected upward with the dotted line emanating from the tip of the time line arrowhead.

The example depicts that all is OK for the first two quantum of the collection process and the detection of an error and a warning for the next two quantum, followed by a return to normal for the fifth and final quantum depicted. When the Shipboard Storage process for the five quantum depicted completes just after the collection of the fifth quantum and the system determined success for this action,

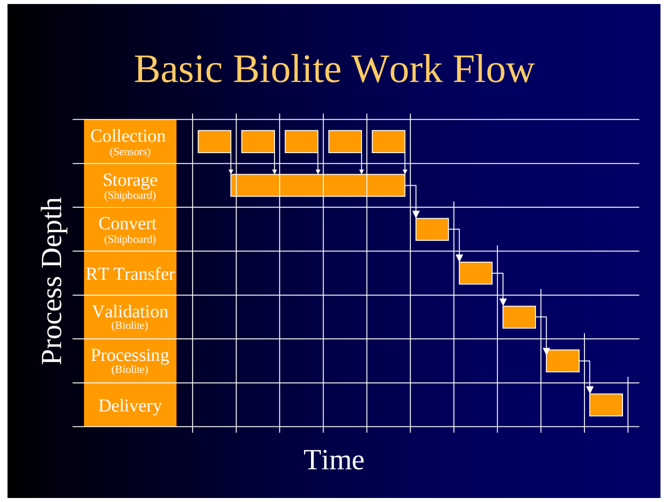

Fig. 6. Logical Flow vs. Time

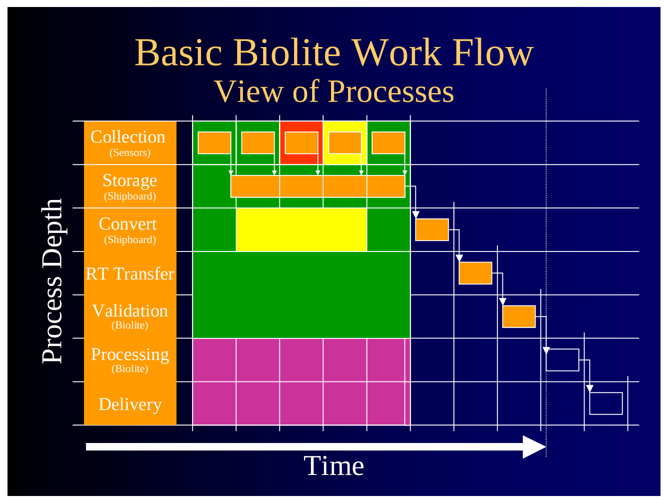

Fig. 7. Logical Coloring of Process Layers

the Storage status values for the five quantum are retroactively set to green. The Shipboard Convert process for the depicted quantum did not occur until some time later and encountered a warning condition. The Real-Time Transfer of these quantum reported success, and the Validation of the data by BIOLITE experts residing at NAVOCEANO also was indicated to be successful. As the data have not yet reached the Processing or Delivery stages, the color is left purple for all statuses for the quantum depicted.

Survey Progress Layer. A survey progress layer may represent one, and only one, process depth. That is, all the dots for a single layer represent the same process or summary level. While the SCV supports the concurrent display of multiple layers, simultaneous display of more than one survey progress layers from the same survey is not recommended. Simultaneous caching of multiple survey progress layers is supported and recommended to facilitate rapid swapping of views.

Summary Layers. Summary layers are provided to enable the assimilation of information from multiple sensor, process, and summary layers. For example, the status of all the sensors required by a survey operation may be processed looking for the status value associated with the highest state

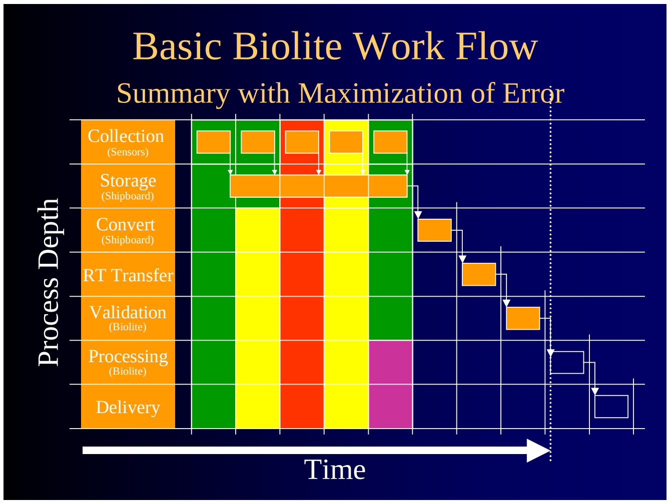

Fig. 8. Summary Layers Created Using the Maximization of Error Function

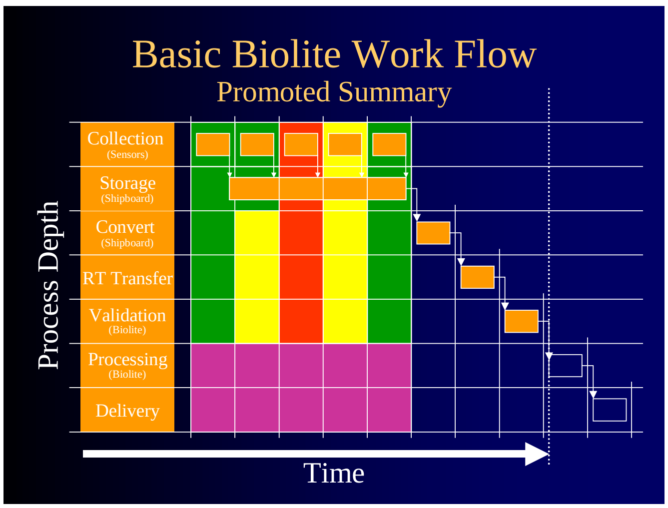

Fig. 9. Coloring of Promoted Summary Layers

(the worst case). Thus, the user may select a single layer that summarizes all these sensors into a single layer. The same technique is available for summarizing process layers. Fig. 8 depicts the results of Fig. 7 summarized in this manner.

A process layer may be summarized with one or more other layers. The summary function supports the ability to promote a dot of the unknown or unmonitored state to the highest value.

This type of promotion, depicted in Fig. 9, allows the unknown state to retain its meaning of unknown (or data have not reached this point yet). For example, summarizing a sensor with a warning status with that of a transportation process that has not yet executed and thus is represented by the unknown state would yield a warning value for normal summarization but a value of unknown when using the "promote unknown" form of summarization. The unmonitored state provides the user with the knowledge that the OK state will never be reached. The "best to hope for" is a white dot. When labeling a layer as the "real-time transport layer," some of the data types may not be transported, and thus a green dot would present an incorrect image of the state of the data. The dot would remain purple until the transfer occurred and was reported to the system, at which time the dot would inherited the worst of caution, error, or severe value, or unmonitored (white) if everything is OK.

Drilling down into information. The SCV supports the selection of two dots to represent the first and last quantum in a time series. Using this concept, the SCV is able to invoke applications on behalf of the user and pass the application layer information (including the selected time range) from the application, and the SCV may be used to display relevant information. This mechanism allows data-specific visualization programs to be synchronized with the SCV.

Fig. 4 depicts an SCV for BIOLITE to the validation process summary level. Note the survey plan illustrates the current planned path, and a series of dots indicates the ship position every 15 minutes. The green dots indicate that data have been collected, converted, transported, and validated by the BIOLITE Code. The purple dots indicate while the data have not yet been validated, no errors were encountered at this time.

VI. SUMMARY

The SLAP, in conjunction with the SCV design, will provide NAVOCEANO with a means to monitor the quality of the underway survey data within 24 hours of data collection. This is a vast improvement over the existing one- to two-month scenario. In addition, it allows configurable access to critical status information of onboard sensor equipment. Diagnosing problems from the SOC helps reduce ship down time and travel costs associated with sending engineers to the ships to resolve mission-critical problems. In addition, the quality of the survey data is made available to NAVOCEANO SMEs for their review as the survey is still in progress. The result is higher quality data being returned to the Office, less rework and editing of the data in house, and as a consequence, faster product turnaround to the customer.